Study the Effects of Atmospheric Pollutants on Invasibility of Panne Vegetation by Invasive Plants

FINAL STUDY PLAN

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ABSTRACT

Indiana Dunes National Lakeshore (INDU) is located downwind of the Chicago-Hammond-Gary area at the southern tip of Lake Michigan, one of the most industrialized areas in the United States. As recently as 1994, this area was responsible for 25percent of the steel manufactured in the United States. Pollutants emanating from this industrial powerhouse are routinely deposited on INDU by wet and dry atmospheric deposition. Pannes are small, nutrient limited, 1 to 4 acres, intra-dunal wetland/upland complexes that are isolated from surface flow by high dunes. Pannes are important because they provide habitat for many habitat-restricted plant, amphibian, reptile and dragonfly species. Seventeen state-listed plant species are found in pannes. Over the past 15 years cattail, common reed and other invasive species have invaded panes. In this study, mesocosm and field investigations will be conducted to determine the levels of heavy metals and nitrogen in pannes, their spatial distribution within a panne and the threshold levels necessary to increase susceptibility of panne vegetation to invader species.

INTRODUCTION

Problem Statement

Pannes are small, nutrient limited, 1 to 4 acre, intra-dunal wetland/upland complexes that are isolated from surface flow by high dunes. Pannes are important because they provide habitat for many habitat-restricted plants as well as sensitive amphibian, reptile and dragonfly species. The 15 pannes at INDU comprise approximately 55 acres (0.3 percent of the park's land area). These unique wetlands are home to 213 different plant species (14.8 percent of total plant species in the park) 17 of which are state-listed plant species (12.6 percent of state-listed plant species at INDU). Based on studies conducted in 1986 (Hiebert et al 1986), invasive species were not prevalent in pannes before 1986. Today, invasive species are present to some degree in all pannes and in some cases are sufficiently dense to have a notable negative impact on native panne vegetation. In one panne, populations of three state listed species present and monitored in permanent plots in the 1980's are now extinct, their habitat occupied by introduced invasive species. Invasive species present in the pannes are *Phragmites australis* (Common Reed), *Phalaris arundinaceae* (Reed Canary grass), *Typha spp*. (Hybrid Cattail), *Lythrum salicaria* (Purple Loosestrife) and *Salsola kali* (Russian Thistle).

A review of the National Atmospheric Deposition Program site on the world wide web (http://nadp.sws.uiuc.edu) and summary reports from CastNet (USEPA 1998) indicate that INDU may be exposed to higher concentrations of atmospheric derived pollutants such as nitrogen compounds and heavy metals than any other National Park. Between 1981 and 2001 the average annual wet deposition of ammonium was 3.93 kg per hectare and that of nitrate 16.3 kg per hectare. Elevated heavy metal levels and elevated nutrient levels may facilitate invasion by new species and cause a shift in wetland plant community structure (Gorham and Gordan 1963; Newman et al. 1998; Galatowisch et al. 2000; Clarke and Baldwin 2002).

Background Information

In the pre-industrial world the dominant nitrogen source for aquatic and terrestrial ecosystems was derived through natural biological processes. Generally, natural processes produced less nitrogen than demanded by terrestrial and aquatic ecosystems and these ecosystems evolved within this nitrogen-limited environment. By 2001, human activity was responsible for 15 times more nitrogen being released into the environment than was released into the environment in 1860 (Cowlings 2001). Thus, today many ecosystems have a surplus of nitrogen. Concurrently, there has been a loss of overall plant diversity, a conversion of notable plant assemblages to those dominated by a few species, and the replacement of native species with exotic species. Examples of species-rich wetlands becoming species poor and dominated by a few nitrophilous species abound in the literature (For example, Ehrenfeld 1983; Aerts and Berendse 1988; Wassen 1989; Verhoeven, J.T.A et. al. 1993).

In addition to nitrogen, ecosystems have been assaulted with numerous other chemicals ranging from heavy metals to sulfur. Plant tolerance to different metals varies widely (Guilizzoni 1991). Elevated levels of heavy metals such as cadmium, lead, copper, zinc, chromium, nickel, manganese and selenium can be toxic to plant cells (Steffens 1990). These metals can cause stunted growth, chlorosis, reduced germination, reduced growth rates, and alter enzymatic processes and nutrient uptake (Bazzaz et al. 1974; Root et al. 1975; Lee et. al. 1976; Barua and Jana 1986). Elevated heavy metal levels and elevated nutrient levels may also cause a shift in wetland plant community structure (Gorham and Gordan 1963; Newman et al. 1998; Galatowisch et al. 2000; Clarke and Baldwin 2002).

One of the most industrialized areas in the United States is the Chicago-Hammond-Gary area at the southern tip of Lake Michigan in northwest Indiana. The area's industrial beginnings can be traced to 1869. Steel production in the Gary-East Chicago, Indiana area dates back to the 1890's. As recently as 1993, steel producing facilities located on the 70 kilometers of shoreline extending from Michigan City, Indiana to the state of Illinois represented approximately 25 percent of the nation's steel-making capacity (Botts 1993). Steel manufacturing, along with other processes such as coal, coke and fuel oil combustion; casting and coating; plating and polishing; and the production of inorganic pigments augment the atmospheric pollutant load along this 70 kilometer shoreline (Winchester and Nifong 1971; USEPA 1995).

In 1966, Indiana Dunes National Lakeshore (INDU) was carved out of the urban/industrial complex on the southern shore of Lake Michigan. Unfortunately, INDU was located on the extreme eastern edge of the shoreline and due to prevailing westerly winds has been exposed to over a century of atmospheric pollutant deposition (Souch et. al. 2002). This deposition of pollutants continues today. The average pH of rainfall in Indiana Dunes National Lakeshore is 4.5, which qualifies it as among the most acidic in the United States (NADP 1998). A review of the National Atmospheric Deposition Program site on the world wide web (http://nadp.sws.uiuc.edu) and summary reports from CastNet (USEPA 1998) indicate that INDU may be exposed to higher concentrations of atmospheric derived pollutants such as nitrogen compounds and heavy metals than any other National Park. Between 1981 and 2001, the average annual wet deposition of ammonium was 3.93 kg per hectare and that of nitrate 16.3

kg per hectare. Studies have confirmed elevated levels of heavy metals in the Great Marsh, an inter-dunal wetland with organic enriched soils (Cole et al 1990; Perkins et al 2000; Dollar et al 2001; Mastalerz et al 2001). Parker et al (1978) and Miller and McFee (1983) found elevated concentrations of heavy metals in organic enriched soils throughout northwestern Indiana.

Indiana Dunes National Lakeshore has astounding floristic diversity. At 15,000 acres it is one of the smaller National Parks, but with 1,445 different species of plants, it is ranked third in floristic richness. The ranges of boreal, prairie, deciduous forest and savanna/woodland species overlap at INDU and coastal relict species, a reminder of past plant migrations, remain in unique niches throughout the National Lakeshore. One hundred and forty state-listed plant species, one federal-listed plant species and one federal-listed animal species are found at INDU.

Given the important role that species richness played in its authorization, it is surprising that so few studies have been conducted on the effects of atmospheric derived pollutants on its flora. Wetmore (1986) suggested that air pollutants might have caused mortality of lichens at INDU. A current study by Greg Mueller of the Chicago Field Museum suggests that elevated levels of nitrogen deposition may be related to a smaller proportion of ectomycorrhizae present at INDU than at comparable nature preserves in the Chicago area. There have been no studies on the effects of atmospherically derived pollutants on the vascular vegetation or on ecosystem processes such as native plant recruitment or invasive species recruitment. This knowledge vacuum has prevented the development of guidelines pertaining to management of vegetation communities exposed to high levels of atmospheric pollutants.

Nested within INDU is the West Beach unit. One of West Beach’s most notable features is its intra-dunal wetland/upland complexes known as pannes. At INDU pannes occur within one mile of the shoreline of Lake Michigan. They are considered a globally imperiled habitat by the Nature Conservancy and have been placed on the first tier of conservation targets for recovery by the Chicago Wilderness Biodiversity recovery plan (1999). Pannes are scattered along the eastern and southern dune system of Lake Michigan from Chicago to northern lower Michigan.

A panne is an upland/wetland complex of which 80 to 90 percent is wetland. A panne is completely surrounded by high dunes and is defined by the perimeter described by the base of the dunes. Based on preliminary soil analyses of two pannes at INDU, soil pH ranges from 7.7 to 8.4 and organic matter from 0 percent to 2 percent. At INDU, panne hydrology is a function of precipitation and a seep zone located at its southwest edge. No surface water enters the panne. Panne topography and hydrology are spatially heterogeneous. Seep zones often remain saturated throughout the growing season. Water from the seep zone will pool in the lower portions of the panne, if these areas are not isolated from the seep zone by topographic highs. The lower elevations may exhibit water depths up to 70cm in spring, drying by mid-summer and then reappearing in response to convection storm events.

Pannes are incredibly unique features on the dune landscape. Their limited hydrological inputs, tight nutrient cycles, geographic isolation, and heterogeneous composition make them both biologically diverse and highly sensitive to disruption. The purpose of INDU, as stated in the park’s enabling legislation is to “preserve for the educational, inspirational, and recreational use

of the public certain portions of the Indiana dunes and other areas of scenic, scientific, and historic interest". Pannes are certainly a part of this list.
Invasive species are present to some degree in all pannes. In 50 percent of the pannes, exotic species are sufficiently dense to have a notable negative impact on native panne vegetation. In one panne, habitat occupied by state listed species in the 1980's is now occupied by Common Reed, Hybrid Cattail and Purple Loosestrife (Mason, unpublished NPS data, 1999). Based on studies conducted in 1986 (Hiebert et al. 1986), invasives were not prevalent in pannes before 1986. A decline in species richness can lead to declines in overall levels of ecosystem functions (Naeem et al. 1999).

Why pannes have been invaded is not known. Plants require safe sites to establish (Harper 1977). The fruit of Hybrid Cattail and Common Reed (the prevalent invasive species found in pannes) is characterized by appendages facilitating wind dispersal. Hence, it is likely that fruits of these species have always arrived in the pannes, but due to the absence of safe sites, they were unable to establish. We hypothesize that the accumulation of nitrogen from atmospheric deposition and/or pulse events of nitrogen from atmospheric deposition has generated safe sites for the establishment of invasive species. Examples of events resulting in a pulsed influx of nitrogen are spring snowmelt and summer convection storms.

To our knowledge, the effects of atmospherically derived pollutants on ecosystem processes of wetlands have not been adequately studied. In part, this may be due to the multiple pathways by which pollutants may arrive at a wetland (e.g. atmospheric, overland flow). Because of their position on the landscape, pannes are isolated from all sources of point and non-point pollutants except atmospheric deposition. Also, nitrogen deposition in the pannes is unique in that only the effects of added nitrogen are seen. Soils of pannes are well buffered with calcium so that pH changes leading to the release of aluminum cations in soil, as in the case of poorly buffered high elevation forests, will not be a complicating issue. Therefore, pannes are uniquely suited as laboratories for investigations into the effects of atmospheric pollutants on wetland ecosystem processes.

We propose a series of studies to investigate the concentrations of atmospheric pollutants in the soils of pannes at INDU and the potential effects of these pollutants on increasing the susceptibility of panne vegetation to invader plants. Little is known concerning atmospheric pollutants in dune sands and other surficial deposits at INDU or elsewhere. Heavy metals and nutrients may be spatially distributed in the pannes in accordance with definable physical features. If this is so, and if the presence of heavy metals and/or nutrients reduces the resistance of panne vegetation to invasion, then park managers will be able to identify areas within the pannes that are susceptible to invasion and implement corrective management activity before invading plants are able to establish.

Through a series of field studies and mesocosm studies we will provide answers to the following questions:

1. Is there a difference in heavy metal and nitrogen levels among pannes at Indiana Dunes National Lakeshore?

2. Do pannes at Indiana Dunes National Lakeshore exhibit higher levels of heavy metals and nitrogen than pannes on the eastern shore of Lake Michigan where atmospheric deposition of pollutants is less?

3. Do levels of heavy metals and nitrogen have a spatial component within a panne or are the pollutants uniformly distributed across a panne?

4. Is there a relationship between heavy metal and nitrogen levels found in a panne and the quantity of individuals of an invasive species?

5. Is the quantity of invasive propagules arriving at pannes similar among pannes historically and at present?

6. What is the critical threshold of nitrogen deposition necessary to generate safe sites for establishment of Hybrid Cattail in nutrient limited sand based wetlands?

7. What is the critical threshold of nitrogen deposition necessary to facilitate establishment of Hybrid Cattail in a stand of a dominant panne plant species (*Cladium mariscoides*)?

8. Can the effects of nitrogen accumulation be nullified by management action such as the deposition of sucrose on areas within a panne exhibiting high levels of nitrogen (Carbon would stimulate the growth of denitrifying bacteria, thus, reducing the level of nitrogen available to nitrophilous)?

Specific Objectives:

The proposed work will determine the spatial distribution of atmospherically derived heavy metals and nitrogen in the soils of the unique, nutrient limited, upland/wetland complexes known as pannes. The existing biological and physical resources of 8 pannes will be quantified. Threshold nitrogen levels at which invasion windows for Hybrid Cattail (one of the common invaders of pannes) occur will be determined. A potential management activity to counter nitrogen deposition will be investigated. Maps showing where nitrogen and heavy metals accumulate in a pannes will be created. These maps will help managers identify invasion windows, reduce invasive species search time, and facilitate a more effective use of person hours by managers.

Environmental Planning:

Section 106 clearance for archaeological artifacts is necessary prior to soil disturbance. A Section 106 review was requested in spring 2000 and clearance to conduct sampling in pannes at Indiana Dunes National Lakeshore was provided by the mid-west regional office. Officials at Sleeping Bear Dunes have been contacted and the process to gain environmental clearance to work at Sleeping Bear Dunes has been initiated.

This project falls under categorical exclusion E(6) non-destructive data collection, inventory, study, research, and monitoring activities and is therefore excluded from the National

Environmental Policy Act. Each park will evaluate an environmental screening form and a categorical exclusion form.

Concerning necessary permits for work on state lands, Ms. Wendy Fitzner, supervisor of the permit consolidation unit for the state of Michigan has been contacted. Ms Fitzner has conveyed that based on a verbal description of the project, permit difficulties were unlikely. Ms. Fitzner will be reviewing a written description of the project.

Principal Project Managers:

Daniel Mason, Ph.D (Botanist, National Park Service) and Noel Pavlovic Ph.D. (Plant Ecologist, U.S. Geological Survey) will be in charge of field investigations of panne hydrology, water chemistry, vegetation, seedbank and seedrain. They will also design and execute the mesocosm studies. Mason and Pavlovic have conducted similar types of studies at INDU and on other types of wetlands such as the subtropical wetlands of India and the Florida Everglades. Catherine Souch Ph.D. and, Gabriel Filippelli, Ph.D. (Departments of Geography and Geology, Center for Earth and Environmental Science, Indiana University-Purdue University) will be in charge of analyses of heavy metals and other soil pollutants. Souch and Filippelli have conducted similar investigations on peat based wetlands at INDU and elsewhere in Indiana. William Crumpton Ph.D. with Iowa State University will analyze water samples for their chemistry. Crumpton operates an active water quality laboratory at Iowa State University and routinely conducts water chemistry analyses for state and federal concerns.

STUDY/IMPLEMENTATION PLAN

Approach and Methods:

Four pannes at the West Beach unit will be studied. In addition two pannes at Warren Dunes State Park in Michigan and two pannes at Sleeping Bear Dunes National Park will be sampled. These last two sets of pannes are exposed to less atmospheric pollutants than pannes at INDU (NADP 1998; USEPA 1998), and will be used as controls.

Team members met on October 12, 2003 and visited the 12 pannes at the West Beach unit. Four pannes were selected for study: pannes 3, 4, 6 and 9. These pannes were selected because they represent the entire range of variance in observable physical features of pannes at INDU. Also, the selected pannes extend along the entire length of shoreline where pannes occur. Potential pannes at Warren Dunes and Sleeping Bear Dunes were identified by personal visits and/or consultation with knowledgeable people. Ms. Wendy Fitzner, supervisor of the permit consolidation unit for the state of Michigan, has been contacted concerning necessary permits for work on state lands. A meeting with Mr. Steve Yancho, Chief of Resource Management at Sleeping Bear Dunes, is scheduled for early November. Yancho has expressed an interest in having staff of Sleeping Bear Dunes participate in the monitoring of the two wetlands at Sleeping Bear Dunes.

Each panne will each be stratified in accordance to its physical and vegetative characteristics. Sampling will occur within zones defined by this stratification process. These studies will provide insight to the following questions:

1. Is there a difference in heavy metal and nitrogen levels among pannes at Indiana Dunes National Lakeshore?
2. Do pannes at Indiana Dunes National Lakeshore exhibit higher levels of heavy metals and nitrogen than pannes on the Eastern Shore of Lake Michigan where atmospheric deposition of pollutants is less?
3. Do levels of heavy metals and nitrogen have a spatial component within a panne or are the pollutants uniformly distributed across a panne?
4. Is there a relationship between heavy metal and nitrogen levels found in a panne and the quantity of individuals of invasive species?
5. Is the quantity of invasive propagules arriving at pannes similar among pannes?

Details of the field methods are provided below.

Soil Chemistry:

The intensity of soil sampling at any given panne will reflect the size of the panne and the internal heterogeneity within it. Based on initial reconnaissance of the pannes, soil cores of 5-cm diameter will be extracted at a minimum of 20 points in each panne. Each core will extend to a depth below active soil evolution, which varies across the different zones of pannes. For each panne, several cores will extend into sand below the active soil layer to a depth of at least 30 centimeters.

Cores will be split in half lengthwise and photographed. Stratigraphy and sedimentology (in terms of depth of units, color, grain size, presence and degree of decomposition of organic matter, etc) will be described. Sediment samples will then be taken at 1-cm intervals using a plastic syringe, guided by stratigraphic units, along the vertical profile of one half of the core. Samples will be placed in acid-cleaned ceramic crucibles, weighed, oven-dried at 60C for 2-3 days to remove moisture, and then reweighed. The dried samples will then be ashed in a muffle furnace at 550C for 3 hours. Ashed samples will then be reweighed and the Loss on Ignition (LOI) organic matter content of each sample will be calculated. Samples will then undergo strong acid digestion for metal analysis. Approximately 0.5-1g of ashed sediment will be treated with 40 ml of 2N trace-metal-grade HCl. Sediment sample solutions will be centrifuged and diluted with Milli-Q grade water. Sediment sample solutions will then be analyzed (for the heavy metals Cd, Cr, Cu, Fe, Mn, Ni, Pb, Se and Zn, and for P) by inductively-coupled plasmic atomic emission spectroscopy (ICP-AES) using a Leeman Labs PS-950 with an argon-purged Eschelle spectrometer. Sample introduction will be by ultrasonic nebulization (CETAC Corp. AT-5000+) providing low detection limits. Replicates and blanks will be used to determine detection limits and analytical reproducibility.

A variety of standard soil characteristics will also be determined, in order to understand the soil status of the pannes and what effects this might have on vegetation. These additional characteristics, which will be determined following the standard Methods of Soil Analysis (1986;

A. Klute, editor) protocols, include soil pH, cation exchange capacity, total nitrogen, and major element geochemistry for Ca, Mg, K, Na, and base saturation.

Grain size analyses will also be conducted at 1 cm depth increments on the soil horizons for a sub-set of samples using a Malvern Mastersizer 2000 particle size analyzer. In this process, each sample will be treated with hydrogen peroxide to remove organic matter. Then the sample is analyzed on a Malvern Mastersizer 2000 that calculates the particle sizes based on the angle and intensity of laser light scatter.

All laboratory analyses will be conducted at Indiana University-Purdue University at Indianapolis (IUPUI).

Hydrology:

Surface Water- Surface water depths of the pannes will be monitored for a two-year period. One staff gauge will be strategically positioned in each panne. Water levels at these staff gauges will be measured weekly. Monthly, water levels at permanent points establishing a grid in the panne will be measured. Water depths at each grid point will be regressed on water depths at the staff gauges, thereby providing for each grid point a unique equation allowing prediction of the water depth at the grid point from staff gauge data. These data will allow for development of isopleths depicting areas of similar water depths. The isopleths will be developed using Surfer 8 grid-based mapping software (Golden Software 2002).

Ground Water- Groundwater levels will be measured in a series of shallow monitoring wells which will be installed to a depth of approximately 1m. The wells will be positioned along anticipated groundwater gradients. Depth to groundwater will be measured weekly from March through November at INDU and Sleeping Bear Dunes and biweekly at Warren Dunes. The electronic sensor of a Fisher Water Level Indicator will be fed into the well. The depth at which the water level indicator verifies presence of water will be recorded.

Wells will be constructed using 3.5cm-diameter PVC pipe. Along each of four sides, for a length of 70 cm, 1/8 inch diameter holes will be drilled every 2.5cm. The perforated portion of the PVC pipe will be entirely covered with filter fabric (well sock). A 3cm-diameter augur will be used to shape an opening to a depth of 1 meter. The covered portion of the PVC pipe will be inserted into the hole to a depth of 1meter. Between readings, the 65cm stem will be covered with a 3cm-diameter PVC cap.

Three continuous water level recorders will be used to monitor groundwater fluctuations at 30-minute intervals. One will be placed at panne 6 at INDU, one at Warren Dunes, and the other at Sleeping Bear Dunes.

Water Chemistry:

Water Sampling- Water will be sampled and its chemistry determined in late spring and early autumn of 2004 and in early spring of 2005. Surface water will be collected from each individual pool of water that accumulates in an individual panne with separate analyses conducted on each pool. For each surface pool, approximately 180 ml of water will be collected from three different points with a long handled dip cup and placed in a sterile 550ml whirl-pak bag. The three subsamples will be homogenized prior to laboratory analysis.

Ground water will be collected from four shallow wells that have been strategically positioned to account for heterogeneity in groundwater chemistry. The water in a well will be removed using a small hand pump and discarded. Following recharge of the well, 500 ml of water will be pumped into a 550ml Whirl-pak bag.

Following water collection, the samples will be placed in a cooler with ice and then transported back to the water quality laboratory at Indiana Dunes National Lakeshore. In the laboratory, total hardness, calcium hardness and alkalinity measurements will be conducted on 250ml of the sample. An additional split will be placed in 125 ml bottles for nutrient analyses and preserved by acidification to pH < 2 with H_2SO_4. Conductivity and pH will be determined on the remaining sample using calibrated, portable meters. Acid-preserved samples will be analyzed for total phosphorus, nitrate (NO_3-N) and total nitrogen (TN).

Water Quality Analyses- Analyses for total hardness, calcium hardness, alkalinity, conductivity and pH will be conducted immediately following receipt of the samples at the water quality laboratory at Indiana Dunes National Lakeshore. Analyses for total hardness and calcium hardness will be conducted using the EDTA titrimetric method (Standard Methods 1985). Total alkalinity will be determined by titration with a standard sulfuric acid solution (1.6N) to an end point pH as evidenced by the color change of a methyl red/bromcresol green indicator solution. Conductivity and pH will be determined with Fisher and Hach water probes, respectively.

Acid-preserved samples will be mailed to Iowa State University, where under the direction of Dr. William Crumpton, they will be analyzed for nutrients. Total phosphorus will be determined using persulfate digestion/colorimetry (Ebina et al. 1983, APHA 1995). Nitrate (NO_3-N) and total nitrogen (TN) will be determined using second derivative spectroscopy (Crumpton et al. 1992).

Vegetation:

Vegetation studies will document species present and percent cover in 1m square quadrats. The vegetation of each panne will be evaluated in 4 to 5, south to north transects and at least 2 west to east transects. These compass bearing will ensure that transects will intersect zones of landscape heterogeneity. The position of the first transect will be located by selection of a random number. Transects that are sequential to the randomly chosen transect will be positioned at an equal distance from the randomly chosen transect and from each other. For each transect, the vegetation will be evaluated at two-meter intervals. Transect placement by randomization of the first transect followed by equal distance between transects will facilitate vegetation mapping using spatial analyses. Limited distance between quadrats is recommended due to the sharp physical ecotones present in pannes. For each quadrat, a species list will be compiled and species cover estimated using a modified Domin-Krajina cover-abundance scale (Mueller-Dombois and Ellenberg 1974). The number of quadrats evaluated will be based on the area of each panne. An agglomerate hierarchical and divisive cluster analysis will be used to classify vegetation types.

In mid-June and early September, a search will be conducted in each panne for invasive species. When an invasive species is found its position will be record using GPS. If more than one individual is present, the number will be quantified through direct counts or estimated by stem counts in 0.5-meter square quadrats.

Seedbank:

Seed of invasive species stored in the soil will be evaluated by the seedling assay method. Sampling intensity will be adjusted for each panne to reflect its area. At each sample point, 10 soil cores (5.0cm in diameter and 30cm length) will be extracted with a soil-probe. The cores will be divided into three 10cm sections. Cores from the same soil depth will be homogenized and 6 subsamples selected for germination. Three sub-samples will be kept saturated and three subsamples will be kept inundated by approximately 6cm of water.

Seed germination will take place in 16cm high and 20cm diameter plastic buckets. Each bucket will be pierced with four 1/8-inch holes near the bottom of the outer wall. For saturated samples, the plastic bucket will be filled with 9cm of sterilized sand followed by 3 cm of sterilized potting medium and then 2cm of seedbank soils. For inundated samples, the plastic bucket will be filled with 4cm of sterilized sand followed by 3cm of sterilized potting medium and then 2cm of seedbank soil. The buckets will be randomly placed into 1.5x1.5m tanks with a drip irrigation system. The tank water level will be adjusted so that water remains at least 1.5 cm below the tops of the buckets. The drip irrigation system prevents alga buildup in the tanks and overheating during the summer months.

Seedbank sampling will take place in early April with germination occurring from mid-April through September. Seedbank germination will take place in the greenhouse at the Indiana Dunes National Lakeshore’s wetland plant propagation center.

Seedrain:

Seed trapping activities will determine the quantity of invasive species seed arriving at each panne. For each panne, sticky seed traps will be positioned at 20 strategic points. The seed trap platform will be comprised of a 25x25cm piece of quarter inch plywood attached to a 1-meter long post. The post with the plywood will be driven into the ground by 70 cm such that the platform is 30cm above the surface of the panne. A 20x20cm piece of transparent paper will be sprayed with Tanglefoot. Tanglefoot is a permanently sticky petroleum gel that will hold seeds that drop onto it. Every two weeks the seedtraps will be inspected using a headset magnifier. If seed are observed on the trap, the sticky trap will be removed, replaced with a new sticky trap and inspected closer in the laboratory under an Olympus SZ40 dissecting scope. The seed present on the sticky trap will be identified to species and counted. If seed are not present, the sticky trap will be replaced as necessary.

Mesocosm Studies:

Mesocosm studies will be conducted to determine in a controlled fashion the interactions between nitrogen deposition levels and panne invasion by nitrophilous species. Specifically the following questions will be addressed:

1. What is the critical threshold of nitrogen deposition necessary to generate safe sites for establishment of Hybrid Cattail in nutrient limited sand-based wetlands?
2. Does the critical threshold of nitrogen deposition necessary to generate safe sites for establishment of Hybrid Cattail in nutrient limited sand-based wetlands differ depending on characteristics of the plant community being invaded?
3. Can the decline in invasive resistance due to nitrogen accumulation be nullified by management action such as the deposition of sucrose on areas within a panne exhibiting high levels of soil nitrogen (Carbon would stimulate the growth of denitrifying bacteria which then would reduce the level of nitrogen, or compete with nitrophilous plants for nitrogen.)?

Mesocosm studies are commonly used as controlled studies to determine ecosystem response to a forcing function of concern (Odum 1984; Kangas and Adey 1996).

Mesocosm Design- The mesocosm will be a Rubbermaid 189-liter storage tank. The tank is 132cm X 78cm X 63cm. The mesocosm has a reinforced ribbing and a drain plug at its base. The mesocosm complex will be comprised of 5 rows (blocks) of 10 mesocosms. The mesocosms will be buried to 30 cm and the excavated soil placed around the periphery of the exposed mesocosm. Fifteen centimeters of Number 53 limestone will be placed in the base of each mesocosm, followed by 27 centimeters of sterile sand and then 10 centimeters of sand mixed with sterile peat. Sterile sand and sterile peat will be mixed proportionally to provide a sand-based soil with 1 to 2 percent organic matter. Denitrifying microbial populations will be introduced to each mesocosm by sprinkling two liters of interstitial marsh water onto the mesocosm. Interstitial marsh water will be acquired through the pumping of it from shallow ground wells. A pressurized irrigation system will be linked to each mesocosm through the drain plug at the mesocosm's base. Water will be adjusted by a ball valve such that the seepage rate of water to the mesocosm's surface will be similar to water loss from evaporation. A timer will turn water off at sunset and on two hours after sunrise. A drain hole of 1.5 cm in diameter and 1.5 cm above the soil surface will be present at each end of the mesocosm.

Experimental Design- Mesocosm studies will be conducted as a three by three factorial with five replications occurring within a randomized block design. Inserting a perforated piece of plastic will split each mesocosm. Each half will be randomly assigned either a heavy or light stand of *Cladium mariscoides* (Twig rush). Based on stem counts, a dense stand of *C. mariscoides* ranges from 500 to 560 stems per meter square and a light stand ranges from 160 to 225 stems per meter square. There will be three levels of nitrogen applications and three levels of carbon applications. The nitrogen levels are as follows: 1. Nitrogen added at atmospheric depositional rates, 2. Nitrogen added at twice atmospheric depositional rates; and, 3. Nitrogen added at three times atmospheric depositional rates. The carbon levels are as follow: 1. Carbon sources absent, 2. Carbon to nitrogen ratio of 15:1 based on atmospheric nitrogen depositional rates; and, 3. Carbon to nitrogen ratio of 30:1 based on atmospheric nitrogen depositional rates. In addition there will be control replicates in which neither nitrogen nor carbon will be added. The 23-year monthly averages of nitrogen deposition as measured at the TNT site at Indiana Dunes National Lakeshore are given in Table 1.

Table 1: The twenty-three year average monthly deposition of ammonium (NH4) and nitrate (NO3) in g/m^2 as measure at the TNT site at Indiana Dunes National Lakeshore.

Month	**NH4**	**NO3**
JAN.	0.027	0.171
FEB.	0.041	0.228
MAR.	0.070	0.241
APR.	0.067	0.211
MAY.	0.054	0.189
JUN.	0.055	0.228
JUL.	0.041	0.217
AUG.	0.038	0.196
SEP.	0.041	0.155
OCT.	0.038	0.151
NOV.	0.036	0.160
DEC.	0.033	0.175

Nitrogen Application- Calcium nitrate and ammonium chloride will be mixed in accordance to the proportions being deposited at Indiana Dunes National Lakeshore and applied as an aqueous solution. Following soil thaw and before soil freezing, one–half of the solution will be applied through 8 feeding tubes scattered randomly throughout the mesocosm. The other half will be applied to the surface by sprinkling. A feeding tube will be comprised of a 7cm length of ¼ inch PVC perforated on the lower 5cm length with four lines of 1/16 inch holes and capped at the base. The feeding tubes will be inserted 5cm into the soil. When soils are frozen, the nitrogen solution will be applied to the surface by sprinkling. Frozen soils are anticipated December through February.

Study Execution- Seed of *C. mariscoides* has been collected from pannes at Indiana Dunes National Lakeshore. The seed will be placed in wet sand and stored cold from November through February. In March the seed will be germinated in five-centimeter cone containers. The mesocosms will be set up in mid-April through Mid-June. In late June, *C. mariscoides* seedlings will be transplanted into the mesocosms. Stem densities will be adjusted as necessary to reach the desired stem density by autumn. Other species colonizing the mesocosms will be removed.

In March, June, and October of 2005, three dispersal events of 100 hybrid Cattail seeds will be simulated. Seed dispersed in the mesocosms in March and June will be collected in the fall of 2004 and refrigerated in wet sand. Seed dispersed in October will be collected in September 2005 and immediately placed in the mesocosms.

Applications of nitrogen to the mesocosms will be initiated in March of 2005. Nitrogen applications will continue through August of 2006. In September of each year, 2004 through 2006, a soil sample will be taken from each mesocosm and analyzed for nutrients, organic matter, pH, and exchangeable cations. Weekly, each mesocosm will be monitored for hybrid Cattail individuals. A Cattail stem will be placed in one of three size classes: seedling, ≤ 30 centimeters in height, and > 30 centimeters in height; and stems counted. In June, August and September of each year stems of *C. mariscoides* will be counted.

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TASKS, ORGANIZATION AND SCHEDULE

SCHEDULE OF TASKS (W=winter; SP= spring; SU= summer; A= autumn)													
	2004				**2005**				**2006**				**2007**
TASK	W	SP	SU	A	W	S	S	A	W	S	**S**	A	
Environmental Compliance	X												
FIELD WORK	**2004**				**2005**				**2006**				**2007**
Hydrology													
Install gauges/wells		X											
Monitor water levels			Weekly				Weekly						
Water Chemisty		X		X		X							
Soil Chemistry													
Sample panne soils		X	X	X									
Sample mesocosm soils				X				X				X	
Seed Rain													
Install traps		X											
Monitor seed traps			X	X	X	X	X	X					
Seed Bank													
Sample seedbank		X											
Seedling assay			X	X	X	X	X	X					
Vegetation													
Quantitative survey			X	X									
Documentation of invasive spp.			X	X		X	X	X					
MEOSOCOSM STUDY	**2004**				**2005**				**2006**				**2007**
Germinate twig rush	X	X											
Setup meoscosms		X	X										
Establish twig rush			X	X									
Cattail dispersal						X	X	X					
Nitrogen deposition							Monthly			Monthly			
Carbon additions							Monthly			Monthly			
Soil chemistry				X				X				X	
Cattail monitoring							Biweekly				Biweekly		
Twig rush monitoring							Monthly				Monthly		
REPORTS													
Initial Completion Report												X	
Final Completion Report													X

Organizations and Personnel Responsible for Designated Tasks	
Primary Project Managers	
Filippelli, Gabriel; Ph.D.	Dept. Geog. & Geo, Center for Earth and Environ. Science; Indiana University-Purdue University
Mason, Daniel; Ph.D.	Botanist; National Park Service
Pavlovic, Noel; Ph.D.	Plant Ecologist; United States Geological Survey
Souch, Catherine; Ph.D.	Dept. Geog. & Geo, Center for Earth and Environ. Science; Indiana University-Purdue University
Other Assistance	
William Crumpton, Ph.D.	Dept. of Botany; Iowa State University
Specific Task Responsibility	
Mason	Mason is responsible for overall project coordination. Mason will work with Sleeping Bear Dunes, Indiana Dunes and the Michigan DNR concerning environmental compliance and permit requirements. Mason will supervise field technicians. He will be in charge of field collection of hydrology, water chemistry samples, seedbank, seedrain and vegetation, setup of the mesocosm study and its execution. Mason will also overseen data entry and assist in data analyses, data interpretation and report writing. Mason will intermediate between project managers and the National Park Service.
Pavlovic,	Pavlovic will interact with Mason pertaining to experimental design of field and mesocosm studies and the procedure of data collection. He will assist in data analyses, data interpretation and report writing.
Souch and Filippelli	Souch and Filippelli will be responsible for sampling soils in the pannes and mesocosms and analyzing them for their chemistry. They will conduct data entry, data analyses, data interpretation and report writing.
Crumpton	Crumpton will conduct chemical analyses on water samples. The water quality laboratory at Iowa State University
Mason; Pavlovic; Souch; Filippelli	As a team, Mason, Pavlovic, Souch and Filippelli will link all collected data and conduct data analyses and data interpretation of these unified data. A summary report will be written in which all questions posed at the beginning of the study are addressed.
Deliverables	
Draft Report	A draft report will be provided for peer review purposes By January 15, 2007
Final Report	Comments from the peer review process will be incorporated and a final report completed by June 15, 2007

DELIVERABLES and other REPORTING REQUIREMENTS

In October 2004 and October 2005 a progress report will be entered into the PMIS system and a hard copy sent to the regional and Washington project representatives. In 2006, an initial completion report will and entered into the PMIS system and in 2007, a final completion report will be entered into the PMIS system. Again hard copies will be submitted to regional and Washington representative. These reports will follow the format provided in guidance from the Washington office.

A final report documenting work conducted and information gained will be submitted to the Air Quality branch in care of Tamara Blett prior to the final completion report for the PMIS system. The goal is for a draft final documentation report by January 2007 and the final documentation report by June 2007.

Organization and authors of the final documentation report will resemble the format provided below.

PANNES OF LAKE MICHIGAN AND THE RELATIONSHIPS BETWEEN ATMOSPHERIC POLLUTANTS AND INVASIVE RESISTANCE OF PANNE VEGETATION

(edited by Mason and Pavlovic)

Introduction ……………………………………………………………… Daum (chief RM)
Chapter 1 Vegetation…………………………………………..…… Mason and Pavlovic
Chapter 2 Seedbanks……………………………………………….. Mason and Pavlovic
Chapter 3 Water Chemistry …………………………………….…….. Crumpton
Chapter 4 Soils ……………………………………………..………. Souch and Fillippe
Chapter 5 Hydrology ……………………………………………….…. Mason
Chapter 6 Effects of nitrogen deposition and carbon additions on invisibility of *Cladium marsicoides* communities by Hybrid Cattail …. Mason and Pavlovic
Chapter 7 Atmospheric derived pollutants and their role in the decline Of panne plant biodiversity………..…………………………………... Mason, Pavlovic, Souch And Fillippee
Chapter 8 Management recommendations ……………………………. Mason, Pavlovic, Souch And Fillippee

In addition to the final documentation report, the data collected will be presented to the scientific and park management community through publications in the peer reviewed literature.